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The immediate influence of implicit motor learning strategies on spatiotemporal gait parameters in stroke patients: a randomized within-subjects design

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Abstract

Objectives: To investigate immediate changes in walking performance associated with three implicit motor learning strategies and to explore patient experiences of each strategy.

Design: Participants were randomly allocated to one of three implicit motor learning strategies. Within-group comparisons of spatiotemporal parameters at baseline and post strategy were performed.

Setting: Laboratory setting.

Subjects: A total of 56 community-dwelling post-stroke individuals.

Interventions: Implicit learning strategies were analogy instructions, environmental constraints and action observation. Different analogy instructions and environmental constraints were used to facilitate specific gait parameters. Within action observation, only videotaped gait was shown.

Main measures: Spatiotemporal measures (speed, step length, step width, step height) were recorded using Vicon 3D motion analysis. Patient experiences were assessed by questionnaire.

Results: At a group level, three of the four analogy instructions ($n = 19$) led to small but significant changes in speed ($d = 0.088$ m/s), step height (affected side $d = 0.006$ m) and step width ($d = -0.019$ m), and one environmental constraint ($n = 17$) led to significant changes in step width ($d = -0.040$ m). At an individual

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level, results showed wide variation in the magnitude of changes. Within action observation ($n=20$), no significant changes were found. Overall, participants found it easy to use the different strategies and experienced some changes in their walking performance.

Conclusion: Analogy instructions and environmental constraints can lead to specific, immediate changes in the walking performance and were in general experienced as feasible by the participants. However, the response of an individual patient may vary quite considerably.

Keywords

Stroke, gait, motor learning, rehabilitation, implicit

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Introduction

Improvement of walking ability after stroke is an essential and extensive part of rehabilitation, especially within physiotherapy.[1] Therapists tend to support gait training by providing verbal instructions to facilitate optimal walking performance.[2] However, many stroke survivors experience deficits in memory, attention, information processing and communication, which can hamper their ability to understand, process and remember verbal information or instructions during therapy and hence may hamper the walking training.[3,4]

Implicit motor learning strategies strive to minimize the use of verbal knowledge and, consequently, are thought to circumvent the need to explicitly understand, process and remember how to perform the motor task.[5,6] Therefore, it has been hypothesized that implicit motor learning makes fewer demands on cognitive resources, especially working memory capacity.[5–7]

Literature describes different applications of implicit motor learning. On one hand, promising results were reported in patients with neurological conditions when analogy instructions, environmental constraints and action observation were used to promote (implicit) motor learning (see section 'Methods' for detailed information on these strategies).[8–12] On the other hand, the provision of detailed verbal knowledge about the motor skill has been described as necessary to improve quality of motor performance in people after stroke.[13,14] In walking, for example, detailed verbal instructions for improving gait could focus on spatiotemporal parameters, such as walking speed, step length and step width. However, it remains unclear whether implicit motor learning strategies aiming to minimize the use of verbal knowledge can also be used to influence specific spatiotemporal gait parameters.

The aim of this study was therefore to investigate immediate changes in walking performance associated with three implicit motor learning strategies and to explore patient experiences of each strategy.

Methods

A short-term randomized design was used to explore immediate changes in walking performance when using three implicit learning strategies (Dutch Trial Register Number: NTR5510). The aim of the study was to investigate what changes in spatiotemporal parameters of the gait pattern are associated with each of these strategies. Therefore, spatiotemporal parameters of participants before and after the use of a strategy were compared for each strategy separately.

People after stroke were invited to participate from December 2015 to December 2016. Ethical approval was provided by the local ethics committees (Zuyderland-Zuyd Ethics Committee 15N-153, Adelante MEC (MEC15-13)) and all participants provided informed consent. Measures were performed at one of two motion capture laboratories at Zuyd University of Applied Sciences or Maastricht University (The Netherlands).

Participants were recruited from two rehabilitation centres, an outpatient clinic of a hospital and from seven physiotherapy private practices in the south of the Netherlands. Furthermore, a call for participation was placed in a local magazine for patients and informal caregivers.

Inclusion criteria were: a stroke (>three months ago), capacity to walk independently with or without a walking aid over 10 m (with a self-selected gait speed <1.2 m/s) and presence of hemiparesis (indicated by a score of <100 on the lower extremity part of the Motricity Index[15] and a score <34 on the lower extremity part of the Brunnstrom Fugl-Meyer assessment[16]). Participants also needed to be able to visit one of the two motion capture laboratories and to have sufficient understanding of the Dutch language.

Exclusion criteria were diagnosed impairments unrelated to stroke but with potential to influence gait pattern (e.g. severe osteoarthritis or amputation of the lower limb), diagnosed additional neurological impairments (e.g. Parkinson's disease).

Every participant was randomly allocated to one of the three strategies (analogy instructions, environmental constraint or action observation) by a researcher blind to the patient's characteristics, based on a computerized randomization schedule (block size 6). Randomization was performed in order to limit risk of selection bias; however, no between-group comparison was performed. The researchers who instructed the patients also performed the measurements and were therefore not blinded for the treatment allocation. The three motor learning strategies were applied using different conditions (Figure 1). Each condition targeted change in a specific spatiotemporal parameter (Supplemental Table 1). These conditions were developed based on piloting. Feasibility of the conditions was assessed by patient representatives.

Analogy instructions

An analogy uses understanding of a known concept or process to facilitate understanding or learning of a new concept or process. During motor learning, the complex structure of the 'to-be-learned' skill can be captured by an appropriate analogy, which is presented to the learner to aid performance of the movements.[17,18] The idea is that the underlying verbal rules of the task are disguised within the analogy and the learner unintentionally (implicitly) employs these rules without gaining explicit knowledge. In this study, four different conditions (analogies) were used to influence primarily walking speed, step length, step width or step height. The analogies were presented to participants pictorially together with a brief instruction (Supplemental Table 1) before the walking trial. Participants were asked to use the analogy during walking. During the walking trial, no further instructions were provided.

Environmental constraints

The environment can be constrained in early stages of the learning process to minimize performance errors.[19] This limits the opportunity for error correction and consequently discourages the need for hypothesis testing that leads to explicit knowledge.[20] In addition, an environment might guide the learner towards a certain movement pattern, without the need for verbal instructions.[21] In this study, three different conditions (constraints) were used to influence primarily speed, step length or step width (Supplemental Table 1). To influence step length, horizontal black and white stripes were projected on the floor, creating a zebra crossing. Participants were instructed to step on the projected stripes. To influence walking speed, a horizontal bar that moved at a constant speed was projected onto the walkway. Participants were instructed to follow the bar without catching up to it. The distance between the stripes and speed of the bar was incrementally increased by 5%, 10% and 15% of baseline performance. To influence step width, a narrow beam was projected onto the floor and participants were instructed to only step on the beam as they walked (decrease step width). The width of the beam was incrementally reduced to be 5%, 10% and 15% narrower than step width at baseline. The participants received brief instructions (Supplemental Table 1) before the walking trial and the projected stripes remained visible during the walking trial.

Action observation

In action observation, the amount of verbal instructions can be limited using modelling (demonstration)

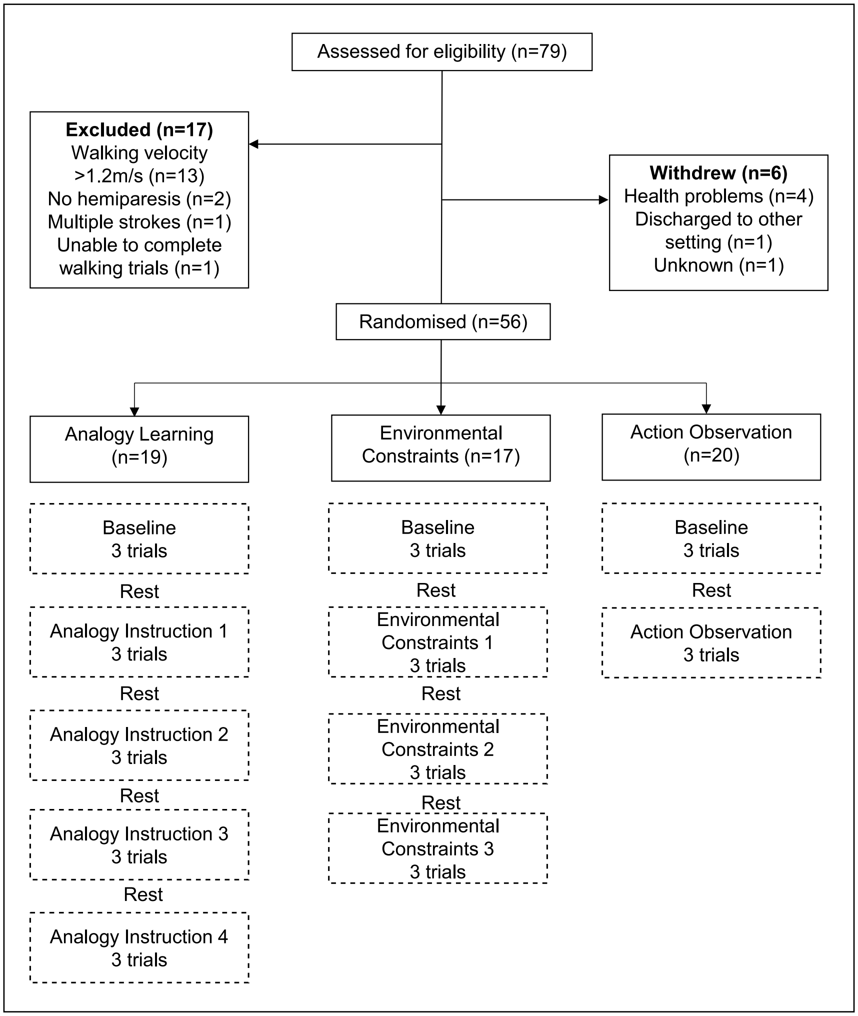

Figure 1. Flow of participants and overview methods.

and video observation.[22] In this study, action observation was applied using only one condition (observation of a short video clip) and the strategy did not target a specific gait parameter. Different video clips of a healthy older male or female walking with different walking aids (e.g. stick, rollator) were used. The video clip that was viewed was chosen based on the gender of the participant and type of walking aid used. The person on the video was shown from a frontal view and a side-view. Participants watched the video and were instructed to try to imitate the walking of the person in the video. During walking, no further instructions were provided.

In all three groups, each condition was repeated three times and a minimum of nine complete strides per condition were included in the analysis. Participants in the analogy group therefore performed 12 trials (3 repetitions of 4 conditions), whereas participants in the environmental constraint group performed 9 trials (3 repetitions of 3 conditions) and participants in the observational group performed 3 trials (3 repetitions of one conditions). Following baseline measurement and each condition, there was a short break in order to limit fatigue (Figure 1). In analogy instructions and environmental constraints, the order of the

Table 1. Operationalization of the spatiotemporal parameters.

Variable	Markers	Calculation
Walking speed	Mean position of the four hip markers to estimate the centre of mass	Dividing the distance walked by the ambulation time
Step length	Heel markers	Distance between heel markers at heel strike
Step height	Ankle marker	Difference in minimal and maximal height within two consecutive heel strikes of the same leg within one step
Step width	Ankle markers	Distance between two ankle markers at double contact
Step length asymmetry	–	Larger step length/(Larger step length + Smaller step length)
Swing time asymmetry	–	Longer swing time/(Longer swing time + shorter swing time)

conditions was counterbalanced (Latin square) in order to offset the possibility of carry-over effects.

We collected the following background data: Motricity Index (voluntary movement activity and maximum muscle strength),[15] Berg Balance Scale (static balance and fall risk),[23] Rivermead mobility index (mobility disability)[24] and Fugl-Meyer Assessment of the lower extremity (ability to make movements outside the synergetic patterns).[16] Cognitive functioning was investigated using the Montreal Cognitive Assessment (detection of mild cognitive problems, scores >26 are considered as normal),[25] the subtest 'news story' of the Rivermead Behavioural Memory Test (memory function)[26] and the D2 attention test (attention span and concentration).[27] Performance on the Rivermead Behavioural Memory Test and the D2 is presented as percentile scores normalized for age, gender (D2, Rivermead Behavioural Memory Test) and educational level (Rivermead Behavioural Memory Test).

The following spatiotemporal parameters were collected in order to assess adaptations to the instructions: speed, step length, step width and step height. The gait parameters (Table 1) were calculated using a custom MATLAB script (version 2012a, The MathWorks, USA). Gait events were determined using an algorithm consistent with Zeni et al.[28] Asymmetry ratios of step lengths and swing time were calculated according to Awad et al.[29] A value of 0.5 reflects perfect symmetry.

The participants' experiences of the strategies were explored using a self-developed questionnaire to gain insight into opinions, feasibility and perceived improvements in walking performance. Responses were recorded using multiple-choice options and free comments. It has been shown that implicit motor learners tend to report fewer verbal rules about their movements during performance than explicit motor learners.[30] After completion of the session, participants were therefore asked to report in detail all rules and techniques they were aware of, or used, during the walking trials. A rule was defined as any statement that contained at least one movement or position of a limb or joint, the velocity of a limb moving, an angle or directions of a joint, placement of the walking aid, changes in the use of the walking aid or changes in step characteristics (bigger steps, wider steps, etc.).

Data on spatiotemporal parameters were collected with a Vicon motion analysis system (Vicon Motion Systems Ltd, Oxford, UK), consisting of eight infrared motion capture cameras running at 200 Hz. The cameras were spaced around a 10 m walkway (Laboratory 1) or a 12 m walkway (Laboratory 2). A total of 35 reflective markers (14 mm) were affixed to participants with adhesive tape according to the Plug-in Gait full body model. Data were processed using Vicon Nexus software version 1.8.5. In a pilot study, the between-laboratory reliability of data was shown to be good to excellent for the spatiotemporal parameters measured (intraclass correlation coefficients (ICCs) between 0.84–0.96, data available on request).

All statistical analyses were conducted in SPSS version 24. Population characteristics and background data are presented using mean values and SD per strategy and for the entire group of participants. Discrete variables are presented using absolute numbers. Statistical testing was used to examine differences between baseline performance and performance during the condition, using a within-group comparison for each of the three strategies (analogy instructions, environmental constraints and action observation) separately. Repeated-measures analysis of variance (ANOVA) and planned contrasts (baseline performances compared to each condition) were used to investigate the analogy instructions over five time points (baseline and four different conditions), the environmental constraints over four time points (baseline and three different conditions) and the action observation over two time points. Non-parametric tests were performed if there was violation of the normality assumption (Friedman's ANOVA combined with Wilcoxon signed-rank tests for multiple comparison and Bonferonni correction). An alpha level of 0.05 was adopted for all tests. Percentage changes from baseline performance for the main outcome parameters are presented using bar charts.

Besides statistical testing, results were analysed in terms of clinical relevance. Individual changes in walking speed were assessed using the clinically important change, which is 0.175 m/s according to Fulk et al.[31] To our knowledge, the clinically important change has not been reported for the other spatiotemporal parameters. Participants' evaluations were analysed descriptively and quotes are used to illustrate their experiences.

Results

A total of 56 participants completed the study (Figure 1). Table 2 presents the demographic information of the participants and the background. In Table 3, mean values for each gait parameter are presented together with results of the statistical tests.

On a group level, three of the four applied analogies led to small but significant changes in walking speed, step height (affected side) and step width. The 'small bridge' instruction (Supplemental Table 1) resulted in a significant mean decrease in step width, accompanied by a decrease in speed and step length (both affected and non-affected legs). The 'traffic light' instruction resulted in the intended increase in walking speed, accompanied by an increase in step length (both affected and non-affected legs) and an increase in step height (both affected and non-affected legs). Step height of both legs and step width increased after participants received the 'deep snow' instruction; however, speed decreased.

In the environmental constraints strategy, only the 'narrow beam' led to the intended change in step width, but speed, step length (affected and non-affected legs) and step height (affected leg only) decreased in this strategy.

In the action observation strategy, walking speed in general decreased. No significant changes were evident for the asymmetry ratios.

In the Supplemental Tables 1-3d, percentage change from baseline in the different conditions is presented visually as bar charts. A broad individual range of changes is apparent (indicated by the error bars). There were participants who responded to the analogy instructions or the environmental constraints with the indented changes in their walking performance. For example, seven participants ($n=3$ environmental constraints, $n=4$ analogy instructions) increased their walking speed by greater than 0.175 m/s, exceeding the clinically important change (maximum increase was 0.66 m/s). These participants on average displayed higher baseline walking speed (mean (SD) 0.72 m/s (0.18)), slightly better functioning of the affected leg (mean (SD) Motricity Index: 71.4 (8.0) and Brunnstrom Fugl-Meyer assessment: 28.6 (4.3)) and superior balance (mean (SD) Berg Balance Scale: 47.6 (5.8)), compared to the mean of all participants. In other participants, the intended spatiotemporal parameter did not change or even changed in the opposite direction (e.g. decrease in walking speed or step length).

Variation in step length change in the 'zebra crossing' condition (environmental constraint) and

Table 2. Demographic information of participants.

	Analogy instruction ($n = 19$)	Environmental constraints ($n = 17$)	Action observation ($n = 20$)	All participants ($N = 56$)
Age in years, mean (SD)	67.0 (11.9)	61.1 (11.9)	63.9 (12.5)	64.1 (12.0)
Gender, *n*				
Male	10	11	11	32
Female	9	6	9	24
Length in cm, mean (SD)	170.4 (8.8)	174.5 (7.2)	170.1 (10.7)	171.5 (9.1)
Weight in kg, mean (SD)	80.7 (19.3)	78.9 (13.7)	77.9 (15.8)	79.15 (16.2)
Side of the stroke, *n*				
Left	10	8	10	28
Right	9	9	10	28
Time post stroke in months, mean (SD)	87.2 (137.5)	89.4 (84.7)	61.8 (57.7)	78.8 (97.9)
Walking aid, *n*				
None	4	5	7	16
Cane	6	7	7	20
Quad cane	3	4	1	8
Rollator	6	1	3	10
Crutch	–	–	2	2
Educational level, *n*				
Elementary education	4	–	–	4
Secondary education	–	8	11	28
Vocational training	9	4	4	8
University	6	5	5	16
Physical functioning mean (SD)				
BBS (0–56)	43.7 (10.9)	42.0 (8.9)	46.2 (11.0)	44.1 (10.3)
MI total score (0–200)	122.1 (37.7)	98.2 (43.7)	109.1 (40.1)	110.2 (40.9)
Lower extremity (0–100)	63.7 (15.7)	56.1 (19.5)	57.8 (15.1)	59.3 (16.8)
Upper extremity (0–100)	58.4 (28.7)	42.1 (30.0)	51.3 (28.5)	50.9 (29.2)
FMA (0–34) ($n = 54$)[a]	23.8 (2.1)	19.9 (7.9)	22.1 (7.9)	22.0 (7.2)
RMI (0–15)	11.8 (2.1)	12.1 (1.9)	11.85 (2.8)	11.93 (2.3)
Cognitive functioning, mean (SD)				
D2	$n = 16$	$n = 17$	$n = 19$	$n = 52$[b]
TN-F	45.4 (12.3)	19.9 (22.3)	44.7 (13.0)	45.79 (12.04)
CP	45.8 (11.8)	27.8 (28.0)	44.5 (14.3)	46.21 (12.04)
RMBT	$n = 17$	$n = 17$	$n = 19$	$n = 53$[c]
Immediate recall	27.7 (26.6)	19.9 (22.3)	19.8 (26.7)	22.4 (25.1)
Delayed recall	36.8 (33.2)	27.8 (28.0)	26.6 (23.3)	30.3 (28.1)
MOCA (0–30)	22.4 (5.5)	24.5 (3.9)	23.5 (4.7)	23.4 (4.8)

RBMT: Rivermead Behavioural Memory Testing; MOCA: Montreal Cognitive Assessment; BBS: Berg balance scale; MI: Motricity Index; FMA: Fugl-Meyer Assessment; RMI: Rivermead Mobility Index; TN-F: the number of all errors relative to the total number of items processed (measure of precision and thoroughness); CP: number of correctly marked characters minus the number of incorrectly marked characters (measure of attention span and concentration ability).
[a]$n = 2$ missing (missed appointment ($n = 1$); test not correct ($n = 1$)).
[b]$n = 4$ missing (did not understand instructions ($n = 2$); not able to read letters ($n = 1$); missed appointment ($n = 1$)).
[c]$n = 3$ missing (did not understand instructions).

Table 3. Spatiotemporal measures (mean (SD)) of the different conditions.

	Analogy instructions (n = 19)						Environmental constraints (n = 17)					Action observation (n = 20)		
	Baseline	Footprints sand	Small bridge	Traffic light	Deep snow		Baseline	Zebra crossing	Narrow beam	Moving bar		Baseline	Video	
Walking speed (m/s)	0.670 (0.23)	0.544 (0.18)*	0.493 (0.19)*	0.758 (0.27)*	0.491 (0.18)*	$F(2.10,37.84) = 18.47$ $P = 0.000$	0.542 (0.25)	0.465 (0.29)	0.375 (0.20)*	0.586 (0.35)	$F(2.28,36.46) = 8.99$ $P = 0.000$	0.686 (0.23)	0.635 (0.18)*	$F(3,57) = 7.95$ $P = 0.011$
Step length affected (m)	0.438 (0.11)	0.430 (0.10)	0.387 (0.10)*	0.471 (0.12)*	0.415 (0.11)	$\chi^2(4) = 32.42$ $P = 0.000$	0.436 (0.08)	0.417 (0.11)	0.380 (0.07)*	0.432 (0.10)	$F(3,48) = 3.97$ $P = 0.013$	0.443 (0.07)	0.441 (0.06)	$F(3,57) = 0.025$ $P = 0.995$
Step length non-affected (m)	0.397 (0.15)	0.409 (0.13)	0.352 (0.14)*	0.436 (0.14)*	0.410 (0.13)	$F(2.46,44.32) = 12.60$ $P = 0.000$	0.328 (0.15)	0.343 (0.16)	0.274 (0.13)*	0.302 (0.17)	$F(3,48) = 5.06$ $P = 0.004$	0.394 (0.12)	0.397 (0.11)	$F(3,57) = 0.11$ $P = 0.956$
Step width (m)	0.247 (0.04)	0.286 (0.07)*	0.224 (0.05)*	0.252 (0.06)	0.266 (0.05)*	$F(1.63,29.26) = 14.44$ $P = 0.000$	0.288 (0.05)	0.298 (0.06)	0.248 (0.06)*	0.297 (0.05)	$F(3,48) = 23.47$ $P = 0.000$	0.250 (0.06)	0.244 (0.05)*	$F(3,57) = 4.70$ $P = 0.005$
Step height affected (m)	0.098 (0.04)	0.098 (0.04)	0.089 (0.04)	0.104 (0.04)*	0.125 (0.8)*	$\chi^2(4) = 29.77$ $P = 0.000$	0.086 (0.04)	0.082 (0.04)*	0.072 (0.03)*	0.079 (0.04)*	$F(2.01,32.16) = 6.92$ $P = 0.003$	0.096 (0.04)	0.095 (0.04)	$F(3,57) = 0.375$ $P = 0.771$
Step height non-affected (m)	0.138 (0.03)	0.140 (0.03)	0.130 (0.03)*	0.144 (0.03)*	0.177 (0.07)*	$F(1.24,22.25) = 10.65$ $P = 0.002$	0.132 (0.02)	0.131 (0.02)	0.122 (0.02)	0.127 (0.02)	$F(2.08,33.30) = 2.70$ $P = 0.080$	0.134 (0.01)	0.134 (0.01)	$F(3,57) = 0.037$ $P = 0.990$
Step length asymmetry	0.56 (0.09)	0.54 (0.05)	0.55 (0.08)	0.54 (0.05)	0.53 (0.04)	$\chi^2(4) = 6.04$ $P = 0.197$	0.61 (0.11)	0.57 (0.10)	0.61 (0.11)	0.63 (0.13)	$\chi^2(3) = 9.47$ $P = 0.024$	0.57 (0.09)	0.56 (0.08)	$T = 23.00$ $P = 0.102$
Swing time asymmetry	0.55 (0.03)	0.55 (0.03)	0.56 (0.05)	0.55 (0.3)	0.55 (0.05)	$\chi^2(4) = 7.18$ $P = 0.127$	0.56 (0.03)	0.57 (0.04)	0.58 (0.04)	0.56 (0.03)	$\chi^2(3) = 7.12$ $P = 0.069$	0.55 (0.03)	0.55 (0.03)	$T = 56.00$ $P = 0.534$

*Significant difference from baseline ($P > 0.05$).

the 'footprints in the sand' condition (analogy instruction) are particularly broad. For instance, two participants were able to increase the step length of their non-affected leg from 2.4 to 14.9 cm (analogy instructions group) and from 2.7 to 19.5 cm (environmental constraints group). In both cases, this resulted in better step-through gait (baseline step length asymmetry 0.94 and 0.90, post/during-condition asymmetry 0.69 and 0.60).

Overall, participants found it relatively easy to walk during the different conditions and did not report a need to think much more than usual (Supplemental Table 2). However, some instructions reminded people of difficult situations in daily life. For example, after using the walking in 'deep snow' analogy, one participant stated that 'in real life I cannot walk through snow with my wheeled rollator', and after using the traffic light analogy, another participant stated that 'in real life I never make it on time to the other side of the road'. In general, participants experienced some change in their walking performance. In the action observation strategy, people frequently reported that they found themselves attending to their 'arm swing' and to 'walking more upright'.

Discussion

The data from this study suggest that in general analogy instructions and environmental constraints can be used to facilitate specific, immediate changes in spatiotemporal gait parameters without providing detailed verbal knowledge. At a group level, three of the four applied analogies led to small but significant changes in walking speed, step height (affected side) and step width. Environmental constraints led to significant changes in step width. For the action observation strategy, no significant changes were found. The use of analogy instructions or environmental constraints changed walking performance in some participants even beyond clinically relevant changes, at least temporarily. However, individual results showed wide variation in the magnitude of changes.

This large individual variation may be explained by the fact that the conditions were pre-defined rather than tailored to the needs of individual participants. For example, in analogy learning, some participants reported that the situations portrayed in the analogies were meaningful for them, whereas other participants stated that these situations were difficult or uncomfortable in daily life. The meaningfulness of the analogy may have influenced the response and consequently the outcome.[32] Within the environmental constraints group, the wide variation within the 'zebra crossing' condition may be explained by large performance differences at baseline. Some participants already walked relatively symmetrically with a step-through gait pattern, whereas others adopted a more asymmetric step-to gait pattern and may therefore have shown greater improvements in step length and step length asymmetry. Similarly, a ceiling effect might have occurred for participants who already had a small ('normal') step width at baseline, causing any further decrease to culminate in an unnatural walking pattern. In action observation, participants often reported that they paid attention to aspects of gait that were either relevant to their own specific walking problem (e.g. stability of the knee joint) or general aspects of gait, such as arm swing and walking more up-right. This variation in interpretation of the instruction might explain the absence of significant specific changes, at least on a group level. In general, these findings suggest that there is a need for motor learning strategies to be tailored to the individual gait pattern and personal preferences and experiences of the patients. The need for tailoring motor learning strategies was recently also confirmed by a randomized controlled trial comparing the effects of internal and external focus instructions.[33]

Gait is a multivariate phenomenon with a pattern across the several parameters, and it is well known that a change of one gait parameter is generally accompanied by changes of other gait parameters.[34] A strength of the study is that a broad set of measures was used in order to measure the overall pattern of change. We were able to detect which additional spatiotemporal parameters might change alongside the primary parameter of interest. For example, an increase of walking speed in the 'traffic light' analogy also led to accompanied changes in step length and height. Furthermore, a decrease in speed was observed in several conditions. It might be that patients require time to fully assimilate a new motor learning strategy and slow down initially in order to focus on the primary aim (e.g. step length).[11]

Another strength of the study is the relatively heterogeneous sample of patients after stroke that was included, especially regarding their cognitive abilities. It is remarkable that all included patients were able to complete the applied intervention even those who were not capable of completing the cognitive tests because of severe cognitive or communicative problems. Regardless of cognitive and communicative impairments, most participants found it easy to use the different strategies.

Next to this strength, some limitations should be considered when interpreting the present results. First, relatively permanent changes in motor behaviour, representing learning, are typically only convincingly evidenced by delayed retention tests or during transfer of a motor skill.[35] The absence of such follow-up testing is a clear limitation of the study. Second, the results of the statistical testing on a group level should be interpreted with caution, because there is a chance of bias as a result of multiple testing. Third, the included sample size did not allow subgroup analysis. For instance, baseline walking speed, balance or motor function might have influenced physical ability to respond to the motor learning strategy.[36,37]

Besides these limitations, physiotherapists and other healthcare professionals involved in motor learning of patients can learn from this study that specific changes in spatiotemporal measures of gait can occur if analogy instructions and environmental constraints are used. The strategies explored in this study were applied using only a single instruction. They might be an efficient therapy option, especially in participants who experience problems with understanding and processing more detailed verbal instructions. Therapists should be aware that using these motor learning strategies does not necessarily prevent patients from consciously controlling their gait and that changing a specific parameter will most likely result in concomitant changes (improvement or deterioration) of additional parameters.

Future research should investigate whether implicit motor learning strategies lead to changes in gait performance that are stable over several sessions, in retention and in real-world overground walking situations. Future studies should also directly compare the effects of implicit motor learning to an explicit control intervention, because in stroke evidence for the superiority of implicit motor learning is inconclusive.[38] This study provides evidence that tailoring motor learning strategies towards individuals' abilities and preferences is important. In practice, therapists seem to take many factors into account when shaping motor learning in practice, which results in highly individualized approaches[39] that cannot be captured within one research paradigm. In order to unravel the complexity of motor learning, different qualitative and quantitative research designs are needed and should probably be combined with systematic observations of which strategy fits the patient's abilities and preferences within clinical practice.

Clinical messages

- Analogy instructions and environmental constraints led to immediate changes in walking performance.
- For action observation, no significant changes were found.
- Individual results showed wide variation in the magnitude of changes.
- The researched strategies seem feasible but need to be tailored to the individual gait problem and preferences of the patients.

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Supplemental material

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